# HYBRID PHOTONIC/ELECTRONIC SWITCHING IN A

## MULTI-CHANNEL NETWORK

## CROSS-REFERENCE TO RELATED APPLICATIONS

[0001]    This is the first application filed for the present invention.

## MICROFICHE APPENDIX

[0002]    Not Applicable.

## TECHNICAL FIELD

[0003]    The present invention relates to switching of traffic in a communications network, and in particular to hybrid photonic/electronic switching in a multi-channel communications network.

## BACKGROUND OF THE INVENTION

[0004]    In the modern communications space, data communications networks are normally deployed on a physical layer network infrastructure constructed using network nodes interconnected by high-speed (frequently optical) data communications links.    In many cases, the nodes and links are arranged in comparatively simple ring architectures, such as Bi-directional Line Switched Rings (BLSRs).    However, data communications networks are rapidly evolving toward more complex topologies, such as multiple highly interconnected rings, and/or mesh networks.    With any network topology, reliability is primarily a product of resource redundancy and rapid physical fault detection and signal switching to avoid failed network resources.

[0005]    Resource    redundancy    refers    to    communications bandwidth capacity and equipment that is held in a dormant

(i.e., unused) state during normal operations of the network, so that it is available to carry traffic in the event of a network resource failure. In BLSR networks, a 1:1 ratio is typically maintained between redundant (usually referred to as "protection") and working capacity. In mesh networks, the ratio between protection and working capacity is frequently 1:N, where N>1. In all cases, at least some redundant bandwidth capacity is maintained for each link, so that upon detection of a network resource failure affecting a working channel of that link, traffic can be switched onto the redundant capacity to bypass the failed resource.

[0006] Resource failure detection and switching of traffic into redundant resources (commonly referred to as "protection switching") can normally be performed by any node of the network, and thus can occur in the nodes immediately adjacent the failed resource. Typically, protection switching is accomplished using either the switch core of the node, and/or special purpose switch elements external to the switch core. An example of the latter arrangement is described in Canadian Patent Application No. 2,275,606, entitled "Automatic Protection Switching System in a Network", which was filed by Ellinas et al. on December 20, 1996 and published on July 2, 1998.

[0007] In all cases, the protection switching function operates to route traffic into a protection channel upon detection of any resource failure affecting normal traffic flow through a link or path. Normally, no distinction is made concerning which resource has failed. Thus, for example, the protection switching function is normally the same, whether the failed resource is a fiber span between two               nodes,               or               an

Optical-to-Electrical/Electrical-to-Optical (OEO) interface traversed by a traffic stream within one of the involved nodes.

[0008]    This arrangement suffers the limitation that the probabilities of failure of the various components forming a link (and in particular OEO interfaces and optical fiber) can vary markedly.   In particular, optical fiber tends to have a higher probability of failure (due to accidental fiber cuts) than an OEO interface, which is enclosed within the controlled environment of a node.   Accordingly, based on their respective different probabilities of failure, an optimum network architecture would include respective different ratios of working to redundant resources for fiber and interfaces.   However, in practice, each channel within a fiber must be hosted by a respective interface. Accordingly, redundant interfaces must necessarily be provisioned in the same ratio as redundant channels within a link.    This typically results in greater numbers of redundant interfaces than is optimum, based on the probability of failure of each interface.   This, in turn, tends to increase the size and cost of provisioning a network node having a desired working bandwidth capacity. The cost of provisioning the required number of interfaces typically constitutes the single largest component of the capital cost of deploying a modern fiber communications network.

[0009]    Accordingly, a system that reduces the cost of a fiber communications network by enabling optimized provisioning of redundant resources remains highly desirable.

## SUMMARY OF THE INVENTION

[0010]    An object of the present invention is to provide a system that enables optimized provisioning of redundant resources in a network node of a multi-channel communications network.

[0011]    Accordingly, an aspect of the present invention provides a system for hybrid electronic/photonic switching of traffic in a node of a communications network.  The system comprises: a plurality of interfaces; an electronic cross-connect (EXC); and a photonic cross-connect (PXC). Each interface is designed to translate a respective traffic stream between corresponding electronic and optical signals.  The EXC selectively maps an electronic signal through a selected one of the interfaces, and the PXC selectively couples an optical signal between the selected interface and a selected one of at least two optical channels of the communications network.

[0012]    In   preferred   embodiments,   the   plurality   of interfaces includes at least two working interfaces and at least one protection interface.  The number of working interfaces may be based on a number of working channels of the communications network, while the number of protection interfaces can be selected based on a probability of failure of a working interface.

[0013]    Each working interface may be designed to translate between an electronic signal and a corresponding optical signal   having   a   substantially   fixed   predetermined wavelength.  The predetermined wavelength may be determined (e.g., during provisioning of the interface in accordance with a design of the communications network) to correspond with a channel wavelength of at least one working channel

of the network.  In such cases, the working interface may include a narrow-band laser designed to generate an optical signal having the predetermined wavelength.

[0014]   Each  protection  interface  may  be  designed  to translate between an electronic signal and a corresponding optical signal having a selected wavelength, which can be dynamically selected from a set of channel wavelengths of the network.  In such cases, each protection interface may include either one or both of: a wide-band optical detector adapted to detect an optical signal having a wavelength corresponding to any channel wavelength of the network; and a  tunable  laser  adapted  to  generate  an  optical  signal having the selected wavelength.

[0015]   A  controller  may  be  provided  to  implement coordinated control of the plurality of interfaces, the EXC and  the  PXC.   This  arrangement  enables  the  system  to perform  protection  switching  due  to  failure  of  network optical channels independently of protection switching due to failure of a working interface.

[0016]   Thus the controller may include means for detecting a failure of a working interface.  In response to detection of  the  interface  failure,  the  controller  selects  a protection interface for carrying the respective traffic stream of the failed interface.  The EXC is then controlled to re-map the respective electronic signal of the affected traffic  stream  through  the  selected  protection  port. Simultaneously,  the  PXC  is  controlled  to  couple  the respective optical signal of the traffic stream between the selected protection port and a respective optical channel through which the traffic stream is being conveyed.  Where the affected traffic stream is outbound (that is, where the

traffic stream is being converted from electronic to optical signal format) the selected protection port can be tuned to generate the outbound optical signal with a wavelength corresponding to that of the failed working interface. As a result, the traffic stream is re-routed within the hybrid photonic/electronic switching system to bypass the failed working interface, without altering traffic flows within the communications network itself.

[0017] The controller may also include means for detecting a failure of a working channel of the communications network. In response to the detected failure, the controller may determine an alternate optical channel through which a traffic stream affected by the channel failure can be carried. The PXC can then be controlled to couple the respective optical signal of the traffic stream between the working interface and the selected alternate optical channel. As a result, the traffic stream is re-routed within the network to avoid the failed optical channel, without affecting traffic flows through the EXC.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

[0019] FIG. 1 is a block diagram schematically illustrating principle elements and operation of a conventional network node deployed in a communications network; and

[0020] FIG. 2 is a block diagram schematically illustrating principle elements and operation of a network

node in accordance with an embodiment of the present invention.

[0021] It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0022] The present invention provides a system that enables optimized provisioning of OEO interfaces in a network node, by implementing hybrid photonic/electrical switching of traffic. For the purposes of describing the present invention, conventional traffic switching in a typical network node is first described with reference to FIG. 1. This description of prior art traffic switching is then followed by a description of hybrid photonic/electrical traffic switching in accordance with the present invention, with reference to FIG. 2.

[0023] As shown in FIG. 1, a conventional network node 2 comprises an input interface 4 including a plurality of input ports 6 for receiving incoming traffic through respective input channels 8 of the network; an output interface 10 including a plurality of output ports 12 for launching outgoing traffic into respective output channels 14 of the network; an electronic cross-connect (EXC) 16 designed to map electronic signal traffic received through each one of the input ports 6 to any one of the output ports 12; and a controller 18 for controlling operation of the node 2. Typically, two or more channels 8, 14 are multiplexed within a single fiber of the network. In the node illustrated in FIG. 1, four input channels 8 are multiplexed within each of two respective input fibers 20. Similarly, four output channels 14 are

multiplexed within each of two respective output fibers 22. Of course, it will be appreciated that more or fewer channels can be multiplexed within a fiber, as is well known in the art. It will also be appreciated that more than two input and output fibers 20, 22 may be coupled to the node 2.

[0024]    Those skilled in the art will recognize that the block diagram of FIG. 1 presents an "unfolded" illustration of the node, which simplifies description of functional characteristics of the node. In practice, an actual network node of the type illustrated in FIG. 1 will normally be constructed using a folded architecture, in which pairs of input and output ports are mounted together on one or more input/output (I/O) cards. Each I/O card is coupled to the EXC, which operates as a switching backplane to map traffic between appropriate ones of the I/O cards.

[0025]    As is well known in the art, each of the channels within any one fiber has a respective channel wavelength, which enables the various input channels 8 to be optically demultiplexed from their respective input fiber 20, and supplied to a respective one of the input ports 6. A conventional Optical-to-Electrical (OE) interface (not shown) within each input port 6 then converts optical signal traffic within a respective channel 8 into corresponding electrical signals for mapping through the EXC 16. As may be seen in FIG. 1, because channels 8 are independently demultiplexed from each fiber 20, overlapping sets of channel wavelengths can be used in each upstream fiber 20.

[0026]    On the output side of the EXC 16, each output port 12 includes a conventional Electrical-to-Optical (EO)

interface (not shown), which converts an outgoing electrical signal into a corresponding optical signal. The optical signal generated by each EO interface has a wavelength that corresponds to the channel wavelength of the respective output channel 14. Multiple (in this case four) output channels 14, each having a respective different channel wavelength, are then optically multiplexed into an output fiber 22 in a manner known in the art. As may be seen in FIG. 1, because channels are independently multiplexed into each output fiber 22, overlapping sets of channel frequencies can be used in the output fibers 22.

[0027] Using this arrangement, a traffic stream 24 received by the node 2 through an input fiber 20 can be mapped through the node 2 to a selected output fiber 22 in a conventional manner. Thus, in the example of FIG. 1 the traffic stream 24 is optically demultiplexed from the input fiber 20a and supplied to input port 6b. The input port 6b converts the traffic stream 24 into a corresponding electronic signal, which is then mapped through the EXC 16 to an available output port 12d coupled to the selected output fiber 22a. The output port 12d then converts the electronic signal into a corresponding optical signal, which is launched into output channel 14d hosted by the output port 12d.

[0028] In general, port assignments are arbitrary. Accordingly, the respective input and output channels 8, 14 used to convey the traffic stream 24 may have the same, or different channel wavelengths. Furthermore, working and protection channels of the network can be accommodated by any of the input and output ports 6, 12 of the node 2, without significantly affecting switching

performance.However, as may be seen in FIG. 1, ports (and their associated OEO interfaces) must be provided on a one-for-one basis for each channel. Accordingly, for all practical purposes, "working" and "protection" ports (and OEO interfaces) are necessarily allocated in the same ratio as working and protection channels, in spite of the fact that the probability of failure of any one port (or OEO interface) is significantly less that that of a fiber link.

**[0029]** The present invention enables optimized provisioning of network resources, by providing a hybrid photonic/electronic switching system in which working and protection OEO interfaces can be allocated independently of working and protection channels. FIG. 2 is a block diagram schematically illustrating principle elements and operation of a network node in accordance with an embodiment of the present invention.

**[0030]** In general, the hybrid photonic/electronic switching system 26 of the present invention comprises a plurality of OEO interfaces 28, 30 for translating respective traffic streams between an electronic signal and an optical signal having a selected channel wavelength; an electronic cross-connect (EXC) 32 for mapping the electronic signal through the interface; and a photonic cross-connect (PXC) 34 for coupling the optical signal between the interface and a selected channel of the network. A control system 36 comprising any suitable combination of hardware and/or software can be provided for controlling operation of the interfaces 28, 30, EXC 32 and PXC 34. This arrangement can be implemented for either (or both) inbound or outbound traffic streams as desired. In the embodiment of FIG. 2, hybrid photonic/electronic

switching in accordance with the present invention is implemented for both inbound and outbound traffic.

[0031]    As in the prior art node illustrated in FIG. 1, input and output interfaces 28 and 30 are shown separately in order to facilitate description of the operation of the system 26. In practice, the interfaces 28 and 30 will normally be provided in pairs, with one or more pairs provisioned on a common I/O card. In addition, the embodiment of FIG. 2, interface protection resources are provisioned on a "per interface" basis. However, it will be appreciated, however that the methods of the present invention can equally be used to provide protection on a "per I/O card" basis, if desired.

[0032]    On the input side of the EXC 32, a plurality of Optical/electronic (OE) interfaces 28 are provided for converting respective inbound optical signals into corresponding electronic signals for mapping through the EXC 32. Thus, for example, an inbound traffic stream 38 received by the system 26 through upstream channel 8c of input fiber 20a is coupled by the PXC 34 to OE interface OE-3 28c. Typically, an OE interface includes a broadband optical detector capable of detecting optical signals having any channel wavelength. In these circumstances, the PXC 34 can couple the inbound optical signals from channel 8c of input fiber 20a to any arbitrary one of the plurality of OE interfaces 28. Accordingly, the control system 36 can select one of the OE interfaces 28 during set-up of the communications path 38, and then control the PXC 34 to couple the selected OE interface (in this case OE-3 28c) to an appropriate one of the input channels (in this case channel 8c of fiber 20a).

[0033]   Optimized provisioning of input-side resources of
the system 26 can be accomplished by suitably selecting the
number of OE interfaces 28.   In particular, a number of
"working" OE interfaces can be provided based on the number
of upstream working channels, and one or more "protection"
OE interfaces provided based on a probability of failure of
any  one  of  the  "working"  OE  interfaces.   As  may  be
appreciated, because any OE interface can receive optical
signals at any channel wavelength, it is not necessary to
specifically  designate  or  provision  OE  interfaces  as
"working" or "protection".   Instead, the control system 36
can control the PXC 34 to couple the appropriate upstream
channel 8 to an available OE interface 28 as a "working"
interface.   If that "working" OE interface subsequently
fails, then any other available OE interface 28 can be
dynamically selected as the "protection" interface, and the
PXC 36 controlled to couple the upstream channel 8 to the
newly selected "protection" interface.  Simultaneously, the
EXC 32  can  be  controlled  to  re-map  the  corresponding
electronic  signal  through  the  selected  "protection"
interface,  and  so  restore  traffic  flow  through  the
communications path 38.

[0034]   For  example,  assume  that  protection  and  working
channels should be provisioned on a 1:1 ratio, based on a
probability of failure of a fiber link.   In this scenario,
the eight upstream channels 8 of FIG. 2 would normally be
divided into four input working channels (e.g., in input
fiber 20a),   and   four   input   protection   channels   (in
fiber 20b).  Assume further that "protection" and "working"
OE interfaces should ideally be provisioned on a 1:8 ratio,
based on the probability of failure of an OE interface.  An
optimized provisioning of OE interfaces can be achieved by
providing five OE interfaces, consisting of four "working"

OE interfaces (one for each of the working channels) and one "protection" OE interface. This yields a ratio of 1:4 between protection and working OE interfaces, which more closely matches the ideal 1:8 ratio than would be possible in the prior art network node of FIG. 1.

[0035]   As shown in FIG. 2, the output side of the EXC 32 follows a pattern that generally mirrors that described above for inbound traffic. In particular, a plurality of Electronic/Optical (EO) interfaces 30 are provided for converting respective outbound electronic signals into corresponding optical signals, which are then coupled through the PXC 34 to a selected output channel 14. In the example of FIG. 2, electrical signal traffic of communications path 38 is mapped through the EXC 32, converted into an optical signal by EO interface EO-1 30a, and then coupled through the PXC 34 to channel 14e of output fiber 22b.

[0036]   As with the input side of the EXC 32, optimized provisioning of interface resources can be accomplished by suitably selecting the number of EO interfaces 30. In particular, a number of "working" EO interfaces 30 can be provided based on the number of downstream working channels, and one or more "protection" EO interfaces provided based on a probability of failure of any one of the working EO interfaces. This arrangement enables the same optimization of protection to working EO interfaces, independent of the provisioned ratio of protection to working channels, as was described above with respect to the input side of the EXC 32. For example, working and protection downstream channels may be provided in a ratio of 1:1 (i.e., 4 protection channels for 4 working channels), while protection and working EO interfaces can

be provided in a ratio of 1:4 (i.e., 1 protection EO interface for 4 working EO interfaces). However, unlike the OE interfaces 28, the working and protection EO interfaces will normally be provisioned in accordance with the design of the network, as described below.

[0037] As is well known in the art, each EO interface incorporates a laser that generates the outbound optical signal. As is also known in the art, such a laser can be designed to be tunable over a range of wavelengths. However, it is possible to reduce the cost of an EO interface by restricting the operating range of the laser to a single predetermined wavelength corresponding to (or, more accurately, within a narrow band centered on) the channel wavelength of a selected output channel. Thus the cost of each working EO interface can be reduced by using a narrow-band laser tuned to a selected one of the channel wavelengths of the output channels. In the example of FIG. 2, working EO interfaces EO-1 30a, EO-2 30b and EO-3 30c generate optical signals at wavelengths corresponding to channel wavelengths cw(a), cw(b) and cw(c), respectively. With this arrangement, optical signals can be coupled between a working EO interface and any output channel having the appropriate channel wavelength. Thus the PXC 34 can be controlled to couple optical signals between working EO interface EO-1 30a and either of output channels 14a in fiber 22a or 14e in fiber 22b. Similarly, the PXC 34 can couple optical signals between working EO interface EO-2 30b and either of output channels 14b in fiber 22a or 14f in fiber 22b. The PXC 34 can also couple optical signals between working EO interface EO-3 30c and either of output channels 14c or 14g. As will be appreciated, additional working EO interfaces (not shown) can be provisioned, with

appropriately tuned narrowband lasers, as required to provide at least one working EO interface for each working output channel.

**[0038]**  Optimized provisioning of output resources involves selecting the number of protection EO interfaces based on a probability of failure of each provisioned working EO interface.  In addition, it is also necessary to provide at least one protection interface capable of covering each working interface.  This may be accomplished in a variety a ways, which may be used alone or in combination, as desired.  For example, one or more protection EO interfaces can be provided with a laser that is designed to be tuned over a range of wavelengths.  By suitable selection of respective tuning ranges of each involved protection EO interface, coverage of all of the working channel wavelengths can be provided.  With this arrangement, upon detection of a failure of a working EO interface, a protection EO interface can be tuned (e.g., under control of the control system 36) to the wavelength of the failed working EO interface.  Thereafter, the EXC 32 can be controlled to re-map the communications path 38 through the involved protection EO interface EO-p 30p (as indicated at 40), and the PXC controlled in a complimentary manner to couple optical signals between the protection interface EO-p 30p and the appropriate downstream channel 14.

**[0039]**  An alternative approach is to provide at least one narrow-band protection EO interface for each channel wavelength.  This approach is particularly advantageous in embodiments having multiple output fibers, each of which has the same channel plan (i.e., the number and channels, and the respective channel wavelengths).  Thus each narrow-band protection EO interface covers one channel of

each of the output fibers.  With this arrangement, upon
detection of a failure of a working EO interface, the
control system 36 can select a protection EO interface
having the same wavelength as the failed "working" EO
interface.  Thereafter, the EXC 32 can be controlled to
re-map the communications path 38 through the selected
protection EO interface EO-p 30p (as indicated at 40), and
the PXC controlled in a complimentary manner to couple
optical signals between the protection interface EO-p 30p
and the appropriate output channel 14.

[0040]    In the foregoing description, the present invention
is described with reference to an exemplary embodiment in
which traffic is switched between two upstream and two
downstream fiber links.  For simplicity of description, the
channel plan is the same for each fiber link.

[0041]    However, it will be appreciated that the present
invention can be usefully deployed with virtually any
number of fiber links, and any number of channels per
fiber.   In general, the present invention can provide
hybrid photonic/electronic NxM switching, where N and M are
the number of input and output channels, respectively.  The
values of N and M may, or may not be equal, and can be
arbitrarily large.   For example, known PXC and EXC
technology can be utilized to enable N and M values of 1000
or more.   Furthermore, it will be understood that the
channel plan in any one fiber may be the same, or
different, from that of any other fiber.

[0042]    As described above, the number of working
interfaces is selected based on the number of working
channels of the network (on the input or output sides of
the node, as appropriate).  In some cases (e.g., in a BLSR

network), these working channels may be statically provisioned in association with provisioned protection channels. However, this is by no means a requirement of the present invention. It will be appreciated that the present invention can equally be employed in mesh networks in which working and protection channels can be dynamically allocated based on respective parameters associated with each channel.

[0043] Thus it will be appreciated that the embodiment(s) of the invention described above are intended to be exemplary only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.